MULTIPOLE ANALYSIS FOR PION PHOTOPRODUCTION WITH MAID AND A DYNAMICAL MODELS

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We present results of new analysis of pion photoproduction data obtained with Dynamical and MAID models

During the last few years we have developed and extended two models for the analysis of pion photo and electroproduction, the Dynamical Model [1] (hereafter called Dubna-Mainz-Taipei (DMT) model) and the Unitary Isobar Model [2] (hereafter called MAID). The final aim of such an analysis is to shed more light on the dynamics involved in nucleon resonance excitations and to extract N^* resonance properties in an unambiguous way. For this purpose as a testing ground we will use benchmark data bases recently created and distributed among different theoretical groups.

The crucial point in a study of N^* resonance properties is the separation of the total amplitude (in partial channel $\alpha = \{l, j\}$)

$$t^{\alpha}_{\gamma\pi} = t^{B,\alpha}_{\gamma\pi} + t^{R,\alpha}_{\gamma\pi} \tag{1}$$

in background $t^{B,\alpha}_{\gamma\pi}$ and resonance $t^{R,\alpha}_{\gamma\pi}$ contributions. In different theoretical approaches this procedure is different, and consequently this could lead to different treatment of the dynamics of N^* resonance excitation. As an example we will consider the two different models: DMT and MAID.

In accordance with Ref.[1], in the DMT model the $t^{B,\alpha}_{\gamma\pi}$ amplitude is defined as

$$t^{B,\alpha}_{\gamma\pi}(DMT) = e^{i\delta_\alpha}\cos\delta_\alpha \left[v^{B,\alpha}_{\gamma\pi} + P\int_0^\infty dq' \frac{q'^2\, R^{(\alpha)}_{\pi N}(q_E, q')\, v^{B,\alpha}_{\gamma\pi}(q')}{E - E_{\pi N}(q')} \right], \tag{2}$$

where $\delta_\alpha(q_E)$ and $R^{(\alpha)}_{\pi N}$ are the πN scattering phase shift and full πN scattering reaction matrix, in channel α, respectively, q_E is the pion on-shell momentum. The pion photoproduction potential $v^{B,\alpha}_{\gamma\pi}$ is constructed in the same way as in Ref.[2] and contains contributions from the Born terms with an energy dependent mixing of pseudovector-pseudoscalar (PV-PS) πNN coupling and t-channel vector meson exchanges. In the DMT model $v^{B,\alpha}_{\gamma\pi}$ depends on 7 parameters: The PV-PS mixing parameter Λ_m (see Eq.(12) of Ref.[2]), 4 coupling constants and 2 cut-off parameters for the vector mesons exchange contributions.

In the extended version of MAID, the S, P, D and F waves of the background amplitudes $t_{\gamma\pi}^{B,\alpha}$ are defined in accordance with the K-matrix approximation

$$t_{\gamma\pi}^{B,\alpha}(\text{MAID}) = \exp{(i\delta_\alpha)}\,\cos\delta_\alpha v_{\gamma\pi}^{B,\alpha}(q,W,Q^2)\,, \tag{3}$$

where $W \equiv E$ is the total πN c.m. energy and $Q^2 = -k^2 > 0$ is the square of the virtual photon 4-momentum. Note that in actual calculations, in order to take account of inelastic effects, the factor $\exp{(i\delta_\alpha)}\cos\delta_\alpha$ in Eqs.(2-3) is replaced by $\frac{1}{2}[\eta_\alpha \exp{(2i\delta_\alpha)}+1]$, where both the πN phase shifts δ_α and inelasticity parameters η_α are taken from the analysis of the SAID group[3].

From Eqs. (2) and (3), one finds that the difference between the background terms of MAID and of the DMT model is that pion off-shell rescattering contributions (principal value integral) are not included in the background of MAID. From our previous studies of the P wave multipoles in the (3,3) channel [1] it follows that they are effectively included in the resonance sector leading to the dressing of the $\gamma N\Delta$ vertex. However, in the case of S waves the DMT results show that off-shell rescattering contributions are very important for the E_{0+} multipole in the $\pi^0 p$ channel. In this case they have to be taken into account explicitly. Therefore, in the extended version of MAID we have introduced a new phenomenological term in order to improve the description of the π^0 photoproduction at low energies,

$$E_{corr}(MAID) = \frac{\Delta E}{(1+B^2 q_E^2)^2}\,F_D(Q^2)\,, \tag{4}$$

where F_D is the standard nucleon dipole form factor, $B = 0.71$ fm and ΔE is a free parameter which can be fixed by fitting the low energy π^0 photoproduction data. Thus the background contribution in MAID finally depends on 8 parameters. Below $\pi^+ n$ threshold for both models we also take into account the cusp effect due to unitarity, as it was described in Ref.[4], i.e.

$$E_{cusp} = -a_{\pi N}\,\omega_c\,ReE_{0+}^{\gamma\pi^+}\sqrt{1-\frac{\omega^2}{\omega_c}}\,, \tag{5}$$

where ω and $\omega_c = 140$ MeV are the π^+ c.m. energies corresponding to $W = E_p + E_\gamma$ and $W_c = m_n + m_{\pi^+}$, respectively, and $a_{\pi N} = 0.124/m_{\pi^+}$ is the pion charge exchange amplitude.

For the resonance contributions, following Ref.[2], in both models the Breit-Wigner form is assumed, i.e.

$$t_{\gamma\pi}^{R,\alpha}(W,Q^2) \;=\; \bar{\mathcal{A}}_\alpha^R(Q^2)\,\frac{f_{\gamma R}(W)\Gamma_R\,M_R\,f_{\pi R}(W)}{M_R^2-W^2-iM_R\Gamma_R}\,e^{i\phi_R}\,, \tag{6}$$

where $f_{\pi R}$ is the usual Breit-Wigner factor describing the decay of a resonance R with total width $\Gamma_R(W)$ and physical mass M_R. The phase $\phi_R(W)$ in Eq. (6) is introduced to adjust the phase of the total multipole to equal the corresponding πN phase shift δ_α.

The main subject of our study in the resonance sector is the determination of the strengths of the electromagnetic transitions described by the amplitudes $\bar{\mathcal{A}}_\alpha^R(Q^2)$. In general, they are considered as free parameters which have to be extracted from the analysis of the experimental data. In our two models we have included contributions from the 8 most important resonances, listed in the Table 1. The total number of $\bar{\mathcal{A}}_\alpha^R$ amplitudes is 12 and they can be expressed also in terms of the 12 standard helicity elements $A_{1/2}$ and $A_{3/2}$. Thus, to analyze experimental data we have a total of 19 parameters in DMT

N^*		MAID current	MAID HE fit	DMT HE fit	PDG2000
$P_{33}(1232)$	$A_{1/2}$	-138	-143	—	-135± 6
	$A_{3/2}$	-256	-264	—	-255± 8
$P_{11}(1440)$	$A_{1/2}$	-71	-81	-77	-65± 4
$D_{13}(1520)$	$A_{1/2}$	-17	-6	-7	-24± 9
	$A_{3/2}$	164	160	165	166± 5
$S_{11}(1535)$	$A_{1/2}$	67	81	102	90± 30
$S_{31}(1620)$	$A_{1/2}$	0	86	37	27± 11
$S_{11}(1650)$	$A_{1/2}$	39	32	34	53± 16
$F_{15}(1680)$	$A_{1/2}$	-10	5	10	-15± 6
	$A_{3/2}$	138	137	132	133 ± 12
$D_{33}(1700)$	$A_{1/2}$	86	119	107	104± 15
	$A_{3/2}$	85	82	74	85± 22
PV-PS mixing:	Λ_m	450	406	302	
	ΔE	2.01	1.73	—	
	χ^2/d.o.f.	11.5	6.10	6.10	

Table 1. Proton helicity amplitudes (in $10^{-3}\,GeV^{-1/2}$), values of the PV-PS mixing parameter Λ_m (in MeV) and low-energy correction parameter ΔE (in $10^{-3}/m_{\pi^+}$) obtained after the high-energy (HE) fit

and 20 parameters in MAID. The final results obtained after the fitting of the high-energy (HE) benchmark data base with 3270 data points in the photon energy range $180 < E_\gamma < 1200$ MeV are given in Table 1.

For the analysis of the low-energy (LE) data base with 1287 data points in the photon energy range $180 < E_\gamma < 450$ MeV in the DMT model we used only 4 parameters: The PV-PS mixing parameter and 3 parameters for the $P_{33}(1232)$ and $P_{11}(1440)$ resonances. In MAID we have one more parameter due to the low energy correction given by Eq. (4). The final results for the helicity elements and the E2/M1 ratio (REM) are given in Table 2. In Table 3 we summarize our results and show the χ^2 obtained for different channels and different observables after fitting the LE and HE data bases. Note that the largest χ^2 in the LE fit we get for differential cross sections and target asymmetries in $p(\gamma,\pi^0)p$. Similar results were obtained practically in all other analyses. A detailed compari-

N^*		MAID current	MAID LE fit	DMT LE fit	PDG2000
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	$A_{3/2}$	-256	-265	—	-255± 8
$P_{11}(1440)$	$A_{1/2}$	-71	-81	-93	-65± 4
	REM(%)	-2.2	-1.9	-2.1	-2.5± 0.5
	χ^2/d.o.f.	4.76	4.56	3.59	

Table 2. Proton helicity elements (in $10^{-3}\,GeV^{-1/2}$) and REM=E2/M1 ratio (in %) obtained from the LE fit.

	LE			HE		
Observables	N	MAID	DMT	N	MAID	DMT
$\frac{d\sigma}{d\Omega}(\gamma,\pi^+)$	317	4.68	3.32	871	6.36	5.95
$\frac{d\sigma}{d\Omega}(\gamma,\pi^0)$	354	7.22	5.74	859	6.87	5.85
$\Sigma(\gamma,\pi^+)$	245	2.79	2.57	546	4.57	6.49
$\Sigma(\gamma,\pi^0)$	192	2.22	1.58	488	7.65	7.65
$T(\gamma,\pi^+)$	107	3.28	2.94	265	3.75	4.17
$T(\gamma,\pi^0)$	72	5.18	4.84	241	5.31	5.65
Total	1287	4.56	3.64	3270	6.10	6.10

Table 3. χ^2/N for the cross sections ($\frac{d\sigma}{d\Omega}$), photon (Σ) and target (T) asymmetries in (γ,π^+) and (γ,π^0) channels obtained after LE and HE fit. N is the number of data points

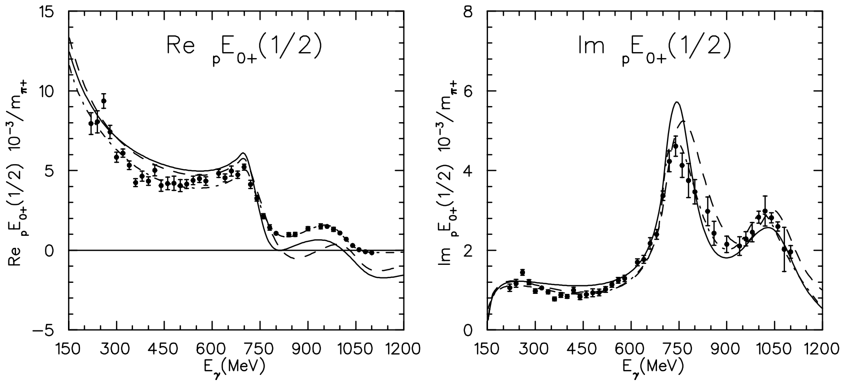

Figure 1. $_pE_{0+}^{1/2}$ multipole obtained after the HE fit using MAID (solid curves) and DMT (dashed curves). The dash-dotted curves and data points are the results of the global and single-energy fits obtained by the SAID group.

son with the results of different theoretical groups is given on the website *http : //gwdac.phys.gwu.edu/analysis/pr_benchmark.html*. Below, in Fig. 1 we show only one interesting example, the E_{0+} multipole in the channel with total isospin 1/2. In this channel contributions from the $S_{11}(1535)$ and $S_{11}(1620)$ resonances are very important. At $E_\gamma > 750$ MeV our values for the real part of the $_pE_{0+}^{1/2}$ amplitude are mostly negative and lower than the results of the SAID multipole analysis. The only possibility to remove such a discrepancy in our two models would be to introduce a third S_{11} resonance. Another interesting result is related to the imaginary part of the $_pE_{0+}^{1/2}$ amplitude and, consequently, to the value of the helicity elements given in Table 1. Within the DMT model for the $S_{11}(1535)$ we obtain $A_{1/2} = 102$ for a total width of 120 MeV, which is more consistent with the results obtained in η photoproduction, than with previous pion photoproduction results obtained by the SAID and MAID groups.

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